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### 4.1 Overview

The detailed description and classification of soil and rock are an essential part of the geologic interpretation process and the geotechnical information developed to support design and construction. The description and classification of soil and rock includes consideration of the physical characteristics and engineering properties of the material. The soil and rock descriptions that are contained on the field logs should be based on factual information. Interpretive information *should not* be included on the field logs, but provided elsewhere, such as in the text of geological, and geotechnical reports. This chapter provides standards for describing and logging soil and rock.

The Unified Soil Classification System, as outlined in **ASTM 2488 – “Standard Practices for Description of Soils (Visual – Manual Procedure)”**, provides a conventional system for classifying soils. However, it alone does not provide adequate descriptive terminology and criteria for identifying soils for engineering purposes. Therefore, the **ASTM** Standard has been modified to account for these additional descriptive terms and criteria. It is not intended to replace the standard but to improve upon it, and make it better understood.

There are numerous rock classification systems, but none of these is universally used. This chapter provides a composite of those classification systems that incorporates the significant descriptive terminology relevant to geotechnical design and construction.

An important facet of soil and rock classification is the determination of what constitutes “rock”, as opposed to extremely weathered, partially cemented, or altered material that approaches soil in its character and engineering characteristics. Extremely soft or decomposed rock that is friable (easily crumbled), and can be reduced to gravel size or smaller by normal hand pressure, should be classified as a soil.

### 4.2 Soil Classification

Soil classification, for engineering purposes, is based on the *distribution* and *behavior* of the fine-grained and coarse-grained soil constituents. Soil descriptions that are contained on the field exploration logs are based on *modified* procedures as outlined in **ASTM 2488**. The visual - manual procedure provided in this standard utilizes visual observation and simple field index tests to identify the characteristics of the soil constituents. Definitions for the various soil constituents can be found in **Table 4-1**. In addition, soil properties that address angularity, consistency/relative density, color, moisture, structure, etc. have been defined.

Soils are divided into four broad categories. These soil categories are coarse-grained soils, fine-grained inorganic soils, organic soils, and peat. The first step in identifying soil is to make a determination regarding which of the four broad categories the soil belongs. The definitions for these broad categories are as follows:

- **Coarse Grained Soils:** Soils that contain 50 % or less of soil particles passing a 0.0030 in. (0.075 mm) opening.
- **Fine Grained Inorganic Soils:** Soils that contain more than 50 % of soil particles passing a 0.0030 in. (0.075 mm) opening.
- **Fine Grained Organic Soils:** Soils that contain enough organic particles to influence the soil properties.

- Peat: Soils that are composed primarily of vegetative tissue in various stages of decomposition that has a fibrous to amorphous texture, usually dark brown to black, and an organic odor are designated as a highly organic soil called peat. Once a soil has been identified as a peat (group symbol **PT**), the soil should not be subjected to any further identification procedures.

Soil Constituent	Description
Boulder	Particles of rock that will not pass through a 12 in. opening.
Cobble	Particles of rock that will pass through a 12 in. opening, but will not pass through a 3 in. opening.
Gravel	Particles of rock that will pass through a 3 in. opening, but will not pass a 0.19 in. (4.75 mm) opening.
Sand	Particles of rock that will pass through a 0.19 in. (4.75 mm) opening, but will not pass a 0.003 in. (0.075 mm) opening.
Silt	Soil that will pass through a 0.003 in. (0.075 mm) opening that is <i>non-plastic</i> or very slightly plastic and exhibits <i>little or no strength</i> when air-dried.
Clay	Soil that will pass through a 0.003 in. (0.075 mm) opening that can be made to exhibit <i>plasticity</i> (putty-like properties) within a range of water contents, and exhibits <i>considerable strength</i> when air-dried.
Organic Soil	Soil that contains enough organic particles to influence the soil properties.
Peat	Soil that is composed primarily of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

**Table 4-1 Soil constituent definition.**

#### **4.2.1 Coarse Grained Soils**

Coarse grained soils are classified as either a gravel or a sand, depending on whether or not the percentage of the coarse grains are larger or smaller than a 0.19 in. (4.75 mm) opening. A soil is defined as a **gravel** when the estimated percentage of the gravel size particles is greater than the sand size particles. A soil is defined as a **sand** when the estimated percentage of the sand size particles are greater than the gravel size particles.

If the soil is classified as a gravel, it is then identified as either clean or dirty. *Dirty* means that the gravel contains an appreciable (greater than 10 %) amount of material that passes a 0.003 in. (0.075 mm) opening (fines), and *clean* means that the gravel is essentially free of fines (less than 10 %). The use of the terms clean and dirty are for distinction purposes only and *should not* be utilized in the description contained on the field log.

If the gravel is clean then gradation criteria apply, and the gravel is classified as either well graded (GW) or poorly graded (GP). Well graded is defined as a soil that has a wide range of particle sizes and a substantial amount of the intermediate particle sizes. Poorly graded is defined as a soil that consists predominately of one particle size (uniformly graded), or has a wide range of particle sizes with some sizes obviously missing (gap graded). Once the grading determination has been made, the classification can be further refined by estimating the percentage of the sand size particles present in the sample.

If the gravel is dirty then it will be important to determine whether the fines are either silt or clay. If the fines are determined to be silt then the gravel will be classified as a silty gravel (GM). If the fines are determined to be clay then the gravel will be classified as a clayey gravel (GC). Once the determination has been made whether the fines are silt or clay, the classification can be further refined by estimating the percentage of sand size particles present in the sample.

If the soil is classified as a sand, the same criteria that were applied to gravels are used - clean or dirty. If the sand is clean, the gradation a criterion is examined in terms of well-graded sand (SW) versus poorly graded sand (SP). Once the grading determination has been made, the classification can be further refined by estimating the percentage of gravel size particles present in the sample. If the sand is dirty, then it will be important to determine whether the fines are silt or clay. If the fines are determined to be silt, then the sand will be classified as a silty sand (SM); conversely, if the fines are determined to be clay, then the sand will be classified as a clayey sand (SC). Once the determination has been made whether the fines are silt or clay the classification can be further refined by estimating the percentage of gravel size particles present in the sample. **Table 4-2** should be used when identifying coarse grained soils.

The coarse-grained soil classification as outlined in **Table 4-2** does not take into account the presence of cobbles and boulders within the soil mass. When cobbles and/ or boulders are detected, either visually within a test pit or as indicated by drilling action/core recovery, they should be reported on the field logs after the main soil description. The descriptor to be used should be as follows:

***with cobbles*** - when only cobbles are present

***with boulders*** - when only boulders are present

***with cobbles and boulders*** - when both cobbles and boulders are present

	Fines	Grading	Silt or Clay	Group Symbol	Sand or Gravel	Description
<b>Gravel</b>	<10%	Well Graded		GW	< 15% Sand	Well graded GRAVEL
	< 10%	Well Graded		GW	≥ 15% Sand	Well graded GRAVEL with sand
	< 10%	Poorly Graded		GP	< 15% Sand	Poorly graded GRAVEL
	< 10%	Poorly Graded		GP	≥ 15% Sand	Poorly graded GRAVEL with sand
	> 10%		Silt	GM	< 15% Sand	Silty GRAVEL
	> 10%		Silt	GM	≥ 15% Sand	Silty GRAVEL with sand
	> 10%		Clay	GP	< 15% Sand	Clayey GRAVEL
	> 10%		Clay	GP	≥ 15% Sand	Clayey GRAVEL with sand
<b>Sand</b>	< 10%	Well Graded		SW	< 15% Gravel	Well graded SAND
	< 10%	Well Graded		SW	≥ 15% Gravel	Well graded SAND with gravel
	< 10%	Poorly Graded		SP	< 15% Gravel	Poorly graded SAND
	< 10%	Poorly Graded		SP	≥ 15% Gravel	Poorly graded SAND with gravel
	> 10%		Silt	SM	< 15% Gravel	Silty SAND
	> 10%		Silt	SM	≥ 15% Gravel	Silty SAND with gravel
	> 10%		Clay	SC	< 15% Gravel	Clayey SAND
	> 10%		Clay	SC	≥ 15% Gravel	Clayey SAND with gravel

Table 4-2 Field description of coarse grained soil classification.

### 4.2.2 Fine-Grained Inorganic Soils

Fine-grained inorganic soils are classified into four basic groups based on physical characteristics of dry strength, dilatancy, toughness, and plasticity. These physical characteristics are summarized in **Table 4-3**. The index tests used to determine these physical characteristics are described in ASTM 2488. Soils that appear to be similar can be grouped together. To accomplish this, one sample is completely described, and the other samples in the group are identified as *similar* to the completely described sample.

When describing and identifying *similar* soil samples, it is generally not necessary to follow all of the procedures for index testing as outlined in ASTM 2488 for those samples.

Soil Group	Dry Strength	Dilatancy	Toughness	Plasticity
Silt (ML)	None to Low	Slow to Rapid	Low	Non-plastic
Elastic Silt (MH)	Low to Medium	None to Slow	Low to Medium	Low to Medium
Lean Clay (CL)	Medium to High	None to Slow	Medium	Medium
Fat Clay (CH)	High to Very High	None	High	High

**Table 4-3 Field identification of fine grained inorganic soils.**

Once the major soil group has been determined, fine grained inorganic soils can be further described by estimating the percentages of fines, sand and gravel contained in the field sample. **Tables 4-4** through **4-7** should be used in describing fine-grained inorganic soils.

### 4.2.3 Organic Fine Grained Soils

If the soil contains enough organic particles to influence the soil properties, it should be identified as an organic fine-grained soil. Organic soils (OL/OH) usually have a dark brown to black color and may have an organic odor. Often, organic soils will change colors, for example black to brown, when exposed to the air. Organic soils will not have a high toughness or plasticity. The thread for the toughness test will be spongy. It will be difficult to differentiate between an organic silt and an organic clay. Once it has been determined that the soil is a organic fine grained soil, the soil can be further described by estimating the percentage of fines, sand, and gravel in the field sample. **Table 4-8** should be used in describing an organic fine-grained soil.

Fines	Coarseness	Sand or Gravel	Description
> 70%	< 15% Plus 0.075 mm		SILT
> 70%	15 to 25 % Plus 0.075 mm	% Sand > % Gravel	SILT with Sand
> 70 %	15 to 25 % Plus 0.075 mm	% Sand < % Gravel	SILT with Gravel
< 70%	% Sand > % Gravel	< 15 % Gravel	Sandy SILT
< 70 %	% Sand > % Gravel	> 15% Gravel	Sandy SILT with gravel
< 70 %	% Sand < % Gravel	< 15 % Sand	Gravelly SILT
< 70 %	% Sand < % Gravel	> 15 % Sand	Gravelly SILT with Sand

**Table 4-4 Field descriptions of silt group (ML) soils.**

Fines	Coarseness	Sand or Gravel	Description
> 70 %	< 15 % Plus 0.003 in. (0.075 mm)		Elastic SILT
> 70 %	15 to 25 % Plus 0.003 in. (0.075 mm)	% Sand > % Gravel	Elastic SILT with Sand
> 70 %	15 to 25 % Plus 0.003 in. (0.075 mm)	% Sand < % Gravel	Elastic SILT with Gravel
< 70 %	% Sand > % Gravel	< 15 % Gravel	Sandy Elastic SILT
< 70 %	% Sand > % Gravel	> 15 % Gravel	Sandy Elastic SILT with Gravel
< 70 %	% Sand < % Gravel	< 15 % Sand	Gravelly Elastic SILT
< 70 %	% Sand < % Gravel	> 15 % Sand	Gravelly Elastic SILT with Sand

**Table 4-5 Field descriptions of elastic silt (MH) group soils.**

Fines	Coarseness	Sand or Gravel	Description
> 70 %	< 15 % Plus 0.003 in. (0.075 mm)		Lean CLAY
> 70 %	15 to 25 % Plus 0.003 in. (0.075 mm)	% Sand > % Gravel	Lean CLAY with Sand
> 70 %	15 to 25 % Plus 0.003 in. (0.075 mm)	% Sand < % Gravel	Lean CLAY with Gravel
< 70 %	% Sand > % Gravel	< 15 % Gravel	Sandy Lean CLAY
< 70 %	% Sand > % Gravel	> 15 % Gravel	Sandy Lean CLAY with Gravel
< 70 %	% Sand < % Gravel	< 15 % Sand	Gravelly Lean CLAY
< 70 %	% Sand < % Gravel	> 15 % Sand	Gravelly Lean CLAY with Sand

**Table 4-6 Field descriptions of lean clay group (CL) soils.**

Fines	Coarseness	Sand or Gravel	Description
> 70 %	< 15 % Plus 0.003 in. (0.075 mm)		Fat CLAY
> 70 %	15 to 25 % Plus 0.003 in. (0.075 mm)	% Sand > % Gravel	Fat CLAY with Sand
> 70 %	15 to 25 % Plus 0.003 in. (0.075 mm)	% Sand < % Gravel	Fat CLAY with Gravel
< 70 %	% Sand > % Gravel	< 15 % Gravel	Sandy Fat CLAY
< 70 %	% Sand > % Gravel	> 15 % Gravel	Sandy Fat CLAY with Gravel
< 70 %	% Sand < % Gravel	< 15 % Sand	Gravelly Fat CLAY
< 70 %	% Sand < % Gravel	> 15 % Sand	Gravelly Fat CLAY with Sand

**Table 4-7 Field description of fat clay group (CH) soils.**

Fines	Coarseness	Sand or Gravel	Description
> 70 %	< 15 % Plus 0.003 in. (0.075 mm)		ORGANIC SOIL
> 70 %	15 to 25 % Plus 0.003 in. (0.075 mm)	% Sand > % Gravel	ORGANIC SOIL with Sand
> 70 %	15 to 25 % Plus 0.003 in. (0.075 mm)	% Sand < % Gravel	ORGANIC SOIL with Gravel
< 70 %	% Sand > % Gravel	< 15 % Gravel	Sandy ORGANIC SOIL
< 70 %	% Sand > % Gravel	> 15 % Gravel	Sandy ORGANIC SOIL with Gravel
< 70 %	% Sand < % Gravel	< 15 % Sand	Gravelly ORGANIC SOIL
< 70 %	% Sand < % Gravel	> 15 % Sand	Gravelly ORGANIC SOIL with Sand

Table 4-8 Field description of organic fine grained soil (OL/OH)group.

#### 4.2.4 Angularity

The field description of angularity of the coarse size particles of a soil (gravel, cobbles and sand) should conform to the criteria as outlined in **Table 4-9**.

Description	Criteria
Angular	Coarse grained particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Coarse grained particles are similar to angular description but have rounded edges
Subrounded	Coarse grained particles have nearly plane sides but have well rounded corners and edges
Rounded	Coarse grained particles have smoothly curved sides and no edges

Table 4-9 Criteria for the field description of angularity.

#### 4.2.5 Consistency and Relative Density

An important index property of cohesive (plastic) soils is its consistency, and is expressed by terms such as very soft, soft, medium stiff, stiff, very stiff, hard, and very hard. Similarly, a significant index property of cohesionless (non-plastic) soils is its relative density, which is expressed by terms such as very loose, loose, medium dense, dense, and very dense. The standard penetration test (ASTM 1586) is an in-situ field test that is widely used to define cohesive soil consistency, and cohesionless soil density. **Tables 4-10 and 4-11** should be used to describe consistency, or relative density.

SPT N (Blows/Foot)	Consistency
0 to 1	Very Soft
2 to 4	Soft
5 to 8	Medium Stiff
9 to 15	Stiff
16 to 30	Very Stiff
31 to 60	Hard
Over 60	Very Hard

**Table 4-10 Consistency of cohesive soils.**

SPT N (Blows/Foot)	Relative Density
0 to 4	Very Loose
5 to 10	Loose
11 to 24	Medium Dense
25 to 50	Dense
Over 50	Very Dense

**Table 4-11 Relative density of cohesionless soils.**

#### 4.2.6 Color

Soil color is not in itself a specific engineering property, but may be an indicator of other significant geologic processes that may be occurring within the soil mass. Color may also aid in the subsurface correlation of soil units. Soil color should be determined in the field at their natural moisture content. The predominant color of the soil should be based on the **Munsell Soil Color Charts**.

#### 4.2.7 Moisture

A visual estimation of the relative moisture content of the soil should be made during the field classification. The field moisture content of the soil should be based on the criteria outlined in **Table 4-12**.

Moisture Description	Criteria
Dry	Absence of moisture; dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water

**Table 4-12 Criteria for describing moisture condition.**

#### 4.2.8 Structure

Soils often contain depositional or physical features that are referred to as soil structure. These features should be described following the criteria as outlined in **Table 4-13**.

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 0.25 in. thick; note thickness and inclination.
Laminated	Alternating layers of varying material or color with layers less than 0.25 in. thick; note thickness and inclination
Fissured	Breaks along definite planes of fracture with little resistance to fracturing.
Slickensided	Fracture planes appear polished or glossy, sometimes striated.
Blocky	Cohesive soil that can be broken down into smaller angular lumps which resists further breakdown.
Disrupted	Soil structure is broken and mixed. Infers that material has moved substantially - landslide debris.
Homogeneous	Same color and appearance throughout.

**Table 4-13 Criteria for describing soil structure.**

#### 4.2.9 HCl Reaction

Calcium carbonate is a common cementing agent in soils. To test for the presence of this cementing agent the soil sample should be tested with dilute hydrochloric acid (HCL). The reaction of the soil sample with HCL should be reported in accordance with the criteria outlined in **Table 4-14**.

HCL Reaction Description	Criteria
No HCL Reaction	No visible reaction
Weak HCL Reaction	Some reaction with bubbles forming slowly
Strong HCL Reaction	Violent reaction with bubbles forming immediately

Table 4-14 Soil reaction to hydrochloric acid.

#### 4.2.10 Test Hole Logging

The protocol for field logging the test hole is to describe the soil properties in the following order:

**Soil Description ⇒ Angularity ⇒ Density ⇒ Color ⇒ Moisture ⇒ Structure ⇒ HCL Reaction**

Some examples of this field logging protocol are as follows:

- Well graded GRAVEL, with cobbles and boulders, sub-rounded, very dense, light brown, wet, homogeneous, no HCL reaction.
- Sandy SILT, medium dense, light gray, moist, laminated, no HCL reaction
- Fat CLAY with sand, medium stiff, dark gray, wet, blocky, no HCL reaction

### 4.3 Rock Classification

Rock classification for engineering purposes consists of two basic assessments; one based on the *intact* properties of the rock, and the other based on the *in situ* (engineering) features of the rock mass.

- **Intact properties** - This assessment is based on the character of the intact rock (hand specimens and rock core) in terms of its genetic origin, mineralogical make-up, texture, and degree of chemical alteration and/or physical weathering.
- **In situ properties** - This assessment is based on the engineering characteristics (orientation, spacing, etc.) of the bounding discontinuities (bedding, joints, foliation planes, shear zones, faults etc.) within the rockmass.

Both assessments are essential engineering characterization of the rock mass, and are the basis for rock slope design and excavation, foundation design on rock, rock anchorage, and characterizing rock quarries.

#### 4.3.1 Intact Properties

Rocks are divided into three general categories based on genetic origin. These categories are *igneous rocks*, *sedimentary rocks*, and *metamorphic rocks*.

### 4.3.1.1 Igneous Rocks

Igneous rocks are those rocks that have been formed by the solidification of molten or partially molten material. Typically, they are classified based on mineralogy and genetic occurrence (intrusive or extrusive). See **Table 4-15** for examples. Texture is the most conspicuous feature (key indicator) of genetic origin (see **Table 4-16**).

In general, coarser grained igneous rocks are intrusive having been formed (solidified) before the molten material has reached the surface; while the finer grained igneous rocks are extrusive and have formed (solidified) after the molten material has reached the surface. Although this generality is true in most cases, it must be stressed that there is no clear line between the two.

A special, but common, class of igneous rock is pyroclastic rocks (See **Table 4-17**). These rocks have been derived from volcanic material that has been explosively or aurally ejected from a volcanic vent.

Intrusive (Coarse- grained)	Primary Minerals	Common Accessory Minerals	Extrusive (Fine Grained)
Granite	Quartz, K-feldspar	Plagioclase, Mica, Amphibole, Pyroxene	Rhyolite
Quartz Diorite	Quartz Plagioclase	Hornblende, Pyroxene, Mica	Dacite
Diorite	Plagioclase	Mica, Amphibole,	Andesite
Gabbro	Plagioclase, Pyroxene	Amphibole	Basalt

**Table 4-15 Common igneous rocks.**

Texture	Grain Size	Genetic Origin
Pegmatitic	Very large; diameters greater than 0.8 in.	Intrusive
Phaneritic	Can be seen with the naked eye	Intrusive or Extrusive
Porphyritic	Grained of two widely different sizes	Intrusive or Extrusive
Aphanitic	Cannot be seen with the naked eye	Extrusive or Intrusive
Glassy	No grains present	Extrusive

**Table 4-16 Igneous rock textures.**

**Table 4-16** should be used only as an aid in determining the possible genetic origin (intrusive versus extrusive) of the igneous rock. For grain size determination and descriptors use **Table 4-23**.

Rock Name	Characteristics
Pyroclastic Breccia	Pyroclastic rock whose average pyroclast size exceeds 2.5 inches and in which <u>angular</u> pyroclasts predominate.
Agglomerate	Pyroclastic rock whose average pyroclast size exceeds 2.5 inches and in which <u>rounded</u> pyroclasts predominate.
Lapilli Tuff	Pyroclastic rock whose average pyroclast size is 0.08 to 2.5 inches.
Ash Tuff	Pyroclastic rock whose average pyroclast size is less than 0.08 inches.

**Table 4-17 Pyroclastic rocks.**

Some extrusive volcanic rocks contain small sub-rounded to rounded cavities (vesicles) formed by the expansion of gas or steam during the solidification process of the rock. The occurrence of these vesicles are to be reported using an estimate of the relative area that the vesicles occupy in relationship to the total area of the sample and the designation as outlined in **Table 4-18**.

Designation	Percentage (by volume) of Total Sample
Slightly Vesicular	5 to 10 Percent
Moderately Vesicular	10 to 25 Percent
Highly Vesicular	25 to 50 Percent
Scoriaceous	Greater than 50 Percent

**Table 4-18 Degree of vesicularity.**

#### 4.3.1.2 Sedimentary Rocks

Sedimentary rocks are formed from preexisting rocks. They are formed by the deposition and lithification of sediments such as gravels, sands, silts, and clays; or rocks formed by the chemical precipitation from solutions (rock salt), or from secretion of organisms (limestone). As indicated above sedimentary rocks are classified based on whether they are derived from clastic sediments or from chemical precipitates/organisms. See **Tables 4-19 and 4-20** for their classification.

Rock Name	Original Sediment
Conglomerate	Sand, Gravel, Cobbles, and Boulders
Sandstone	Sand
Siltstone	Silt
Claystone	Clay
Shale	Laminated Clay and Silt

**Table 4-19 Clastic sedimentary rocks.**

Rock Name	Primary Mineral
Limestone	Calcite
Dolomite	Dolomite
Chert	Quartz

**Table 4-20 Non-clastic sedimentary rocks.**

#### 4.3.1.3 Metamorphic Rocks

Metamorphic rocks are those rocks that have been formed from *pre-existing* rocks when mineral in the rocks have been re-crystallized to form new minerals in response to changes in temperature and/or pressure. Metamorphic rocks are classified based on two general categories; foliated and non-foliated metamorphic rocks. Foliated metamorphic rocks contain laminated structure resulting from the segregation of different minerals into layers parallel to schistosity. Non-foliated metamorphic rocks are generally re-crystallized and equigranular.

Rock Name	Texture	Formed From	Primary Minerals
Slate	Platy, fine grained	Shale, Claystone	Quartz, Mica
Phyllite	Platy, fine grained with silky sheen	Shale, Claystone, Fine grained pyroclastic	Quartz, Mica
Schist	Medium grained, with irregular layers	Sedimentary and Igneous Rocks	Mica, Quartz, Feldspar, Amphibole
Gneiss	Layered, medium to coarse grained	Sedimentary and Igneous Rocks	Mica, Quartz, Feldspar, Amphibole

**Table 4-21 Foliated metamorphic rocks.**

Rock Name	Texture	Formed From	Primary Minerals
Greenstone	Crystalline	Volcanics, Intermediate - Mafic Igneous	Mica, Hornblende, Epidote
Marble	Crystalline	Limestone, Dolomite	Calcite, Dolomite
Quartzite	Crystalline	Sandstone, Chert	Quartz
Amphibolite	Crystalline	Mafic Igneous, Calcium - Iron Bearing Sediments	Hornblende, Plagioclase

Table 4-22 Non-foliated metamorphic rocks.

#### 4.3.1.4 Rock Color

Rock color is not in itself a specific engineering property, but may be an indicator of the influence of other significant geologic processes that may be occurring in the rock mass (e.g. fracture flow of water, weathering, alteration, etc.). Color may also aid in the subsurface correlation of rock units. The color of the rock is based on the *Geological Society of America Rock Color Charts*. Rock color should be determined as soon as the core has been recovered from the test hole.

#### 4.3.1.5 Grain Size

Grain size is defined as the size of the particles or mineral crystals that make up the intact portion of the rockmass. The description of grain size should follow the criteria as set forth in **Table 4-23**.

Grain Size	Description	Criteria
Less than 0.04 inches	Fine grained	Few crystal boundaries/ grains distinguishable in the field or with a hand lens.
0.04 to 0.2 inches	Medium grained	Most crystal boundaries/ grains distinguishable with the aid of a hand lens.
Greater than 0.2 inches	Coarse grained	Most crystal boundaries/ grains distinguishable with the naked eye.

Table 4-23 Grain size.

#### 4.3.1.6 Weathered State of Rock

Weathering is the process of mechanical and/or chemical degradation of the rock mass through exposure to the elements (e.g. rain, wind, ground water, ice, change in temperature etc.). In general, the strength of the rock tends to decrease as the degree of weathering increases. In the earliest stages of weathering only discoloration and slight change in texture occur. As the weathering of the rock advances significant changes occur in the physical properties of the rock mass, until ultimately the rock is decomposed to soil.

The classification of the weathered state of the rock mass is based on six weathering classes (See **Table 4-24**) developed by the International Society of Rock Mechanics (ISRM).

Term	Description	Grade
Fresh	No visible signs of rock material weathering; perhaps slight discoloration in major discontinuity surfaces.	I
Slightly Weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering, and may be somewhat weaker externally than in its fresh condition.	II
Moderately Weathered	Less than half of the rock material is decomposed and/or disintegrated to soil. Fresh or discolored rock is present either as a continuous framework or as corestones.	III
Highly Weathered	More than half of the rock material is decomposed and/or disintegrated to soil. Fresh or discolored rock is present either as discontinuous framework or as corestone.	IV
Completely Weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	V
Residual Soil	All rock material is converted to soil. The mass structure and material fabric is destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

**Table 4-24 Weathered state of rock.**

Alteration is the process that applies *specifically* to the changes in the chemical or mineral composition of the rock due to hydrothermal or metamorphic activities. Alteration may occur in zones or pockets, and can be found at depths far below that of normal weathering. Alteration does not strictly infer that there is a degradation of the rockmass or an associated loss in strength.

Where there has been a degradation of the rockmass due to alteration, **Table 4-24** may be used to describe the alteration by simply substituting the word “*altered*” for the word “*weathered*” for Grade II through Grade V.

#### **4.3.1.6 Relative Rock Strength**

Rock strength is controlled by many factors including degree of induration, cementation, crystal bonding, degree of weathering or alteration, etc. Determination of relative rock strength can be estimated by simple field tests, which can be refined, if required, through laboratory testing. The relative rock strength should be determined based on the ISRM method outlined in **Table 4-25**. Due to the potential for variable rock conditions, multiple relative strength designations may be required for each core run.

Grade	Description	Field Identification	Uniaxial Compressive Strength (Approx)
R0	Extremely Weak Rock	Indented by thumbnail	0.04 to 0.15 ksi
R1	Very Weak Rock	Specimen crumbles under sharp blow with point of geological hammer, and can be cut with a pocket knife.	0.15 to 3.6 ksi
R2	Moderately Weak Rock	Shallow cuts or scrapes can be made in a specimen with a pocket knife. Geological hammer point indents deeply with firm blow.	3.6 to 7.3 ksi
R3	Moderately Strong Rock	Specimen cannot be scraped or cut with a pocket knife, shallow indentation can be made under firm blows from a hammer point.	7.3 to 15 ksi
R4	Strong Rock	Specimen breaks with one firm blow from the hammer end of a geological hammer.	15 to 29 ksi
R5	Very Strong Rock	Specimen requires many blows of a geological hammer to break intact sample.	Greater than 29 ksi

Table 4-25 Relative rock strength.

#### 4.3.1.7 Slaking

Slaking is defined as the disintegration of a rock under conditions of wetting and drying, or when exposed to air. This behavior is related primarily to the chemical composition of the rock. It can be identified in the field if samples shrink and crack, or otherwise degrade upon drying, or being exposed to air for several hours. If degradation of the rock sample occurs, and slaking is suspected; an air-dried sample may be placed in clean water to observe a reaction. The greater the tendency for slaking, the more rapid the reaction will be when immersed in water. This tendency should be expressed on the field logs as *“potential for slaking”*, and can be confirmed through laboratory testing.

#### 4.3.2 In Situ Properties

The in-situ properties of a rock mass are based on the engineering properties of the bounding structure within the rockmass. Structure refers to large-scale (megascopic) planar features which separate intact rock blocks, and impact the overall strength, permeability, and breakage characteristics of the rock mass.

Common planar features within the rockmass include joints, bedding, and faults; collectively called **discontinuities**. These common planar features are defined as follows:

- Joints**- Joints are fractures within the rockmass along which there has been no identifiable displacement.
- Bedding** - Bedding is the regular layering in sedimentary rocks marking the boundaries of small lithological units or beds.
- Faults** - Faults are fractures or fracture zones within the rockmass along which there has been significant shear displacement of the sides relative to each other. The presence of gouge and/ or slickensides *may* be indicators of movement.

When defining the in-situ properties of these planar features (discontinuities) within the rockmass, the recovered rock core from the borehole is examined, and the following information recorded:

- Discontinuity Spacing
- Discontinuity Condition
- Core Recovery
- Rock Quality Designation (RQD)
- Fractures Frequency (FF)
- Voids

#### **4.3.2.1 Discontinuity Spacing**

Discontinuity spacing is the distance between *natural* discontinuities as measured along the borehole. An evaluation of discontinuity spacing within each core run should be made, and reported on the field logs in conformance with the criteria set forth in **Table 4-26**. Mechanical breaks caused by drilling or handling should *not* be included in the discontinuity spacing evaluation.

Description	Spacing of Discontinuity
Very Widely Spaced	Greater than 10 ft.
Widely Spaced	3 ft to 10 ft.
Moderately Spaced	1 ft to 3 ft.
Closely Spaced	2 inches to 12 inches
Very Closely Spaced	Less than 2 inches

**Table 4-26 Discontinuity spacing.**

#### 4.3.2.2 Discontinuity Condition

The surface properties of discontinuities, in terms of roughness, wall hardness, and /or gouge thickness, affects the shear strength of the discontinuity. An assessment of the discontinuities within each core run should be made, and reported on the field logs in conformance with the descriptions and conditions set forth in **Table 4-27**.

Condition	Description
Excellent Condition	Very rough surfaces, no separation, hard discontinuity wall.
Good Condition	Slightly rough surfaces, separation less than 0.05 inches, hard discontinuity wall.
Fair Condition	Slightly rough surface, separation greater than 0.05 inches, soft discontinuity wall.
Poor Condition	Slickensided surfaces, or soft gouge less than 0.2 inches thick, or open discontinuities 0.05 to 0.2 inches.
Very Poor Condition	Soft gouge greater than 0.2 inches, or open discontinuities greater than 0.2 inches.

**Table 4-27 Discontinuity condition.**

#### 4.3.2.3 Core Recovery (CR)

Core recovery is defined as the ratio of core recovered to the run length expressed as a percentage. Therefore:

$$\text{Core Recovery (\%)} = \frac{100 \times \text{Length of Core Recovered}}{\text{Length of Core Run}}$$

These values should be recorded on the field logs on a core run by core run basis.

#### 4.3.2.4 Rock Quality Designation (RQD)

The RQD provides a subjective estimate of rock mass quality based on a modified core recovery percentage from a double or triple tube diamond core barrel. The RQD is defined as the percentage of rock core recovered in intact pieces of 4 inches or more in length in the length of a core run, generally 6 ft in length. Therefore:

$$\text{RQD (\%)} = \frac{100 \times \text{Length of Core in pieces} \geq 4 \text{ inches}}{\text{Length of Core Barrel}}$$

Mechanical breaks caused by drilling or handling should not be included in the RQD calculation. Vertical fractures in the core should not be utilized in the RQD calculation.

#### **4.3.2.5 Fracture Frequency (FF)**

Fracture frequency is defined as the number of *natural* fractures per unit of length of core recovered. The fracture frequency is measured for each core run, and recorded on the field logs as fractures per foot. Mechanical breaks caused by drilling or handling should *not* be included in the fracture frequency count. In addition, vertical fractures in the core should *not* be utilized in the fracture frequency determination.

#### **4.3.2.6 Voids**

Voids are defined as relatively large open spaces within the rockmass caused by chemical dissolution or the action of subterranean water within the rockmass. In addition, voids can be a result of subsurface mining activities. Voids, when encountered, should be recorded on the field logs. Attempts should be made to determine the size of the void by drilling action, water loss, etc.

#### **4.3.3 Test Hole Logging**

The protocol for field logging the test hole is to first describe the *intact* properties if the rockmass followed by the description of the *in-situ* properties:

**[Intact Properties] Rock Name ⇒ Rock Color ⇒ Grain Size ⇒ Weathered State ⇒ Relative Rock Strength. then [In-situ Properties] Discontinuity Spacing ⇒ Discontinuity Condition ⇒ Core Recovery ⇒ RQD ⇒ Fracture Frequency.**

Some examples of this field logging protocol are as follows:

DIORITE, medium light grey (N6), medium grained, slightly weathered, moderately strong rock (R3). **[Intact Properties]** Discontinuities are widely spaced, and in fair condition. CR = 100%, RQD = 80%, FF = 2. **[In-situ Properties]**

BASALT, highly vesicular, dark grey (N3), very fine grained, slightly weathered, fresh, strong rock (R4). **[Intact Properties]** Discontinuities are closely spaced, and in poor condition. CR = 65%, RQD = 40%, FF = 20. **[In-situ Properties]**

SILTSTONE, medium dark grey (N4), very fine grained, slightly weathered, very weak rock (R1), potential for slaking. **[Intact Properties]** Discontinuities are widely spaced, and in fair condition. CR = 100%, RQD = 100%, FF = 1. **[In-situ Properties]**

#### **4.4 References**

*Munsell Soil Color Charts*, 2000, GretagMacbeth, New Windsor, NY.

Geological Society of America, 1991, *Rock Color Charts*, Boulder, CO.